Circular icons to represent absolute values relating to areal features

Philipp Meyer, Thomas Studer, and Susanne Bleisch

FHNW University of Applied Sciences and Arts Northwestern Switzerland, Institute of Geomatics Engineering, Muttenz, Switzerland; philipp.meyer@fhnw.ch, thomas.studer@students.fhnw.ch, susanne.bleisch@fhnw.ch

Abstract: The Atlas of the Ageing Society required methods to represent absolute values relating to areal features. As most of the displays in the atlas employ dots as symbols we aimed at finding methods to represent quantitative values by an arrangement of dots. The arrangements need to work for a range of values and differently shaped areal features. Additionally, they should allow easy comparison of different values within a display. Some options for using dots as symbols on maps exist but none fulfills the specified requirements. We present two algorithms for dot arrangement. One is a squarish arrangement of dots that positions the dots in the center of the surrounding areal feature. The second is based on a regular grid. An inward buffer of the surrounding areal feature is applied to allow the correct number of dots to be contained within the area. Testing the two methods with different values and shapes yields promising results but also shows some limitations. Very large numbers or very small or irregular areal features remain a challenge. The presented methods will be applied and further tested in visualizations for the Atlas of the Ageing Society.

Keywords: Geovisualization, dot graphics, dot maps, areal geographic data, statistical data, circular icons

1. Introduction

Representations of data and information in relation to spatial features such as areas are widely used and well researched. Typical visualizations include density maps or choropleth maps. Dot-based symbolizations for areal data or data related to areas, such as dot density graphics or dot density maps, are used more rarely. Dots are one of the simplest symbols and can be seen as a circular icon or a generalized circular version of an Isotype. In the symbolic case every dot represents a defined fixed value. Counting the dots and multiplying them with the defined dot value, results in the represented values. More challenging is the case where absolute data is to be displayed in relation to specific areas. The 'correct' or rather most direct representation would fill each area with the respective number of dots required to represent the respective value. This is straightforward for a single area and its related value. It can become more difficult for several areas of different sizes and widely varying associated values. A small area may be required to represent a large value and vice-versa. As mentioned before, for readability and clarity still each dot or circular icon needs to be of the same size and represent the same fixed value across a single display.

2. Related Work

2.1 Representing quantities on maps

There are several ways of displaying quantities or absolute values on maps. They all have their advantages and disadvantages. A dot distribution map places a dot where a phenomenon or a defined number of events occurred. If a dot represents more than one phenomenon concurrently, the dot will be positioned in the center of the representing locations (Fig. 1). A dot represents a specific and defined number of these phenomena (Kimerling, 2009). Such a map needs some sort of base map in the background to allow referencing the dots to their real world locations. The shapes shown in the base map serve the orientation and are not directly linked with the displayed data.

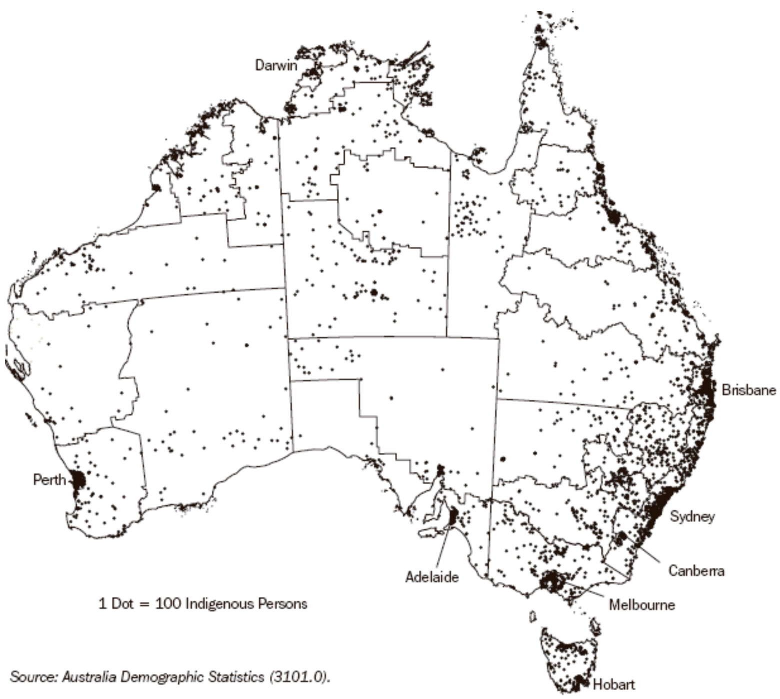

Fig. 1. An example of a dot distribution map. Each dot represents 100 indigenous persons and where approximately they live in Australia. (Australian Bureau of Statistics, 2008)

The strengths of dot distribution maps are in showing geographic patterns, distributions and to some degree also quantities of phenomena. The impression of density can be obtained for bigger areas but it is also possible to extract more detailed information about where exactly a phenomenon occurred. However, often data is not available in enough detail to allow for this representation type. Privacy consideration, i.e. obscuring precise locations, or routine data abstraction methods often aggregate the original data to areal or administrative units. Thus many datasets are only available in an aggregated form without precise location information. From those datasets it is no longer possible to construct dot distribution maps, making it a rarely used representation type.

Another method to represent quantitative values on a map is the use of proportional symbols. Each value is placed at a representative location on the map, generally within the area it relates to, and the size of the symbol represents the value. The use of size to represent quantities is somewhat difficult to perceive (Cleveland & McGill, 1984) and especially proportional circles sizes are generally underestimated (Flannery, 1971). But minimally the perception of order in symbol size is possible.

The method of using a proportional numbers of Isotypes (International System Of Typographic Picture Education) (Neurath, 1936) avoids the issues associated with difficult to interpret proportional symbols. This method arranges or stacks Isotypes in a row or multiple rows and places them on location within or close to the related area or location. Each Isotype represents a certain number of elements or events. Absolute datasets can be visualized with this method and geographical patterns are visible as well. However, as this method uses a fixed grid and size of Isotypes it may happen that the resulting Isotype stacks are bigger than the corresponding area (cf. Fig. 2). This works well as long as there are no neighboring areas whose Isotype stacks are similarly big. In those cases difficult to read overlaps of symbols would occur.

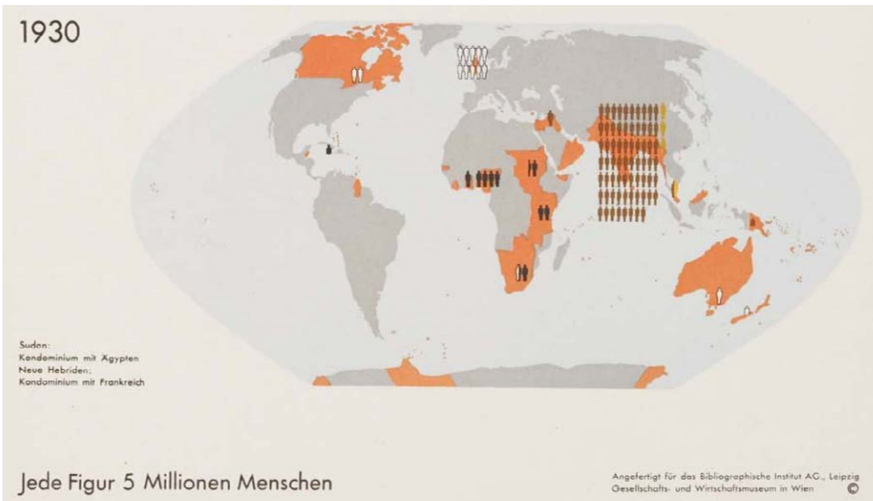

Fig. 2. Absolute quantities of a phenomenon displayed through arranged Isotypes on a map. Each group of Isotypes relates to an area. However, the Isotypes are not generally enclosed by the respective shape but overlap neighboring shapes. (Gesellschaft und Wirtschaftsmuseum in Wien, 1931)

2.2 Isotypes and dots

The use of Isotypes is based on presumably clear symbols that do not need any explanation with words but communicate their meaning through the pictorial symbol used. Different Isotypes need to be clearly different from another to allow easy recognition and avoid misinterpretation by mixing up similar looking symbols. Each Isotype needs to be simple enough so that it can be put in line like letters. Lastly Isotypes are supposed to be in a form that they are not tiring even if seeing lines or stacks of that same symbol.

Lines of these symbols are used because of the first rule of Isotypes:

> "A sign [Isotype] is representative of a certain amount of things; a greater number of signs is representative of a greater amount of things." (Neurath, 1936, S. 73-74)

Symbols of different size are not able to give a clear idea of the effect of a change in the value (Neurath, 1936). As discussed above for the proportional symbols, varying sizes cannot show detailed values but only allow making decisions about magnitude orderings. Thus, when using the Isotype method, not the size of a symbol indicates the amount of things, but rather the number of symbols. The size of a symbol never changes within a display. If we use arrangements of several symbols it is possible to count the numbers to calculated the detailed values of them. Thus, one requirement is that each Isotype or symbol represents a defined number, often even numbers like hundreds. This way it may not be possible to represent the precise numbers but the statements about dimensionality is still interpretable.

A dot is one of the most abstract symbols. It has a neutral shape that is not easily interpreted as something else. Using dots for representing a distribution in a given shape has the advantage of using much less space than other

symbols. That is why we can put more dots into a shape without the problem of overlap (Yau & Hesse-Hujber, 2014). In addition humans find circles (dots) naturally satisfying to look at (Few, 2010).

If we use one or several dots of a single size to represent an amount of things then this is basically in line with the Isotype rules. Neurath (1936) would criticize this decision because a dot is not a self-teaching picture. However, we argue that for maps and for dense displays it may be one of the most practical symbols.

3. Aims and challenges

The work presented here aims to explore the options for representing absolute values within the areal shapes they relate to by arranging small circular symbols or dots. The first two sections of this paper have shown that there are three main challenges to overcome.

The first challenge is the character of data. Even though the data has a spatial component, we usually do not know the actual location of the occurrence of a phenomenon. The data is aggregated to administrative units. We aim for a visualization that is able to deal with aggregated datasets. Secondly, the administrative units the data relate to are often tightly arranged beside each other. This requires a visualization type that fits completely within the shapes without any overlap. For simple shapes this is not difficult to achieve, but it becomes more challenging for small shapes, shapes with holes in them or very irregular shapes. Figure 3 shows three exemplary shapes that may pose some difficulties when trying to place circular symbols within them. The third challenge is the readability and comparability of the visualizations. We aim for a representation that is easy to read and understand without much further information. The numbers of arranged dots are assumed to be easily comparable in their magnitude without actually having to count the dots.

Fig. 3. Three cantons of Switzerland as examples of basic shapes (left), shapes with holes (middle) and irregular shapes (right). (Data origin: swisstopo, 2017)

The goal is to generate dot maps for a range of absolute values to explore the possibilities and limitations of this symbolization method. The dots are used as an Isotype, following the Isotype rules and not for displaying density or distribution maps. To achieve the goal we aim to find methods to place a specific number of dots within the related area. The solution should not only work for a specific dataset and regular shapes but more generally. Technically, we implemented an algorithm that automatically distributes the dots, according to a variety of datasets in a range of shapes.

4. Methods

Two methods are defined that are supposed to satisfy the specified demands. One method is named the "squarish dot arrangement". The squarish dot arrangement is basically a grid arrangement filled from the center while basically adhering to the form of a square and being limited by its surrounding geometry. The second method is called "buffer-based dot arrangement". The buffer-based dot arrangement is a regular grid arrangement too. However, it is

basically depending on the downscaled surrounding shape. For implementing the algorithms for the two methods we used web technologies, specifically JavaScript and for the visualization the library D3.js.

4.1 Squarish dot arrangement

A readable and countable solution is a quadratic arrangement of dots. An equilateral triangle would be more ideal in terms of avoiding gaps between the dots, but a square is more suitable in a cartesian coordinate system (Aschenbrenner 1989 cited in Hey, 2012). Our approach modifies the quadratic arrangement to a squarish arrangement. The squarish form is defined to consist of equal numbers of rows and columns. If this is not possible the number of rows is made to exceed the number of columns by one. The resulting grid will be filled with dots from bottom left to top right. The principle of this arrangement is illustrated in Figure 4 for the values 8 to 13.

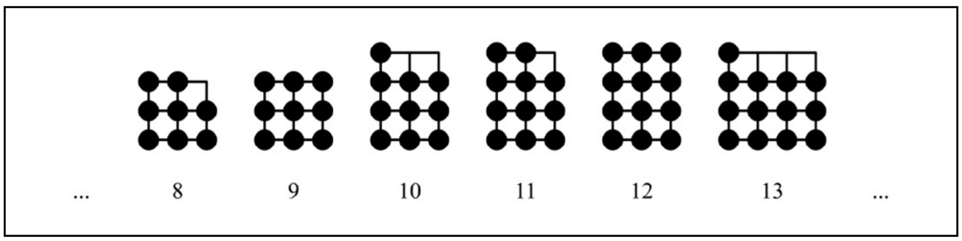

Fig. 4. Squarish dot arrangement with 8 to 13 dots, displayed together with the underlying grid used for the arrangement.

The position of the underlying grid is centered on the center point of the surrounding shape. With this information and a pre-defined distance between dots, the starting point of the grid at the bottom-left corner can be calculated. From there the grid is filled with dots from left to right and from bottom to top.

For regular shapes this works very well, but for irregular shapes it is more complicated. Some dots on the grid could end up lying outside the given shape. Therefore, each dot needs to be checked if it lies within the shape or not. If not, the dot will be skipped and attached to the top row. This could lead to the situation that a defined grid cannot be filled with enough dots. If this is the case, a row or column will be attached and the starting point of the grid is recalculated. This iteration runs until all dots are distributed or the bounding box of the grid exceeds the bounding box of the shape. In this case no visualization is possible for this shape and the defined distance between dots.

4.2 Buffer-based dot arrangement

The buffer-based dot arrangement uses a regular grid and tries to consider the shape of the surrounding area. Regular arrangement of dots are easy to perceive and compare (Hake et al. quoted in Hey, 2012). Instead of increasing and decreasing the distance between the dots until the defined number of dots is reached, we resize the basic surrounding shape until the right amount of dots are placed within the respective shape.

This method starts with finding the shape with the biggest dots to area ratio. That area is then filled with the defined number of dots arranged in a grid so that the distance between dots is maximal. This resulting maximal distance between dots is then applied to the other shapes so that the grid cell size is the same everywhere (Fig. 5 left). All following shapes are resized with an inward buffer that itself needs to contain the right number of dots (Fig. 5 middle). This is an iterative process to find the right size of buffer that corresponds with the number of dots to be displayed (Fig. 5 right).

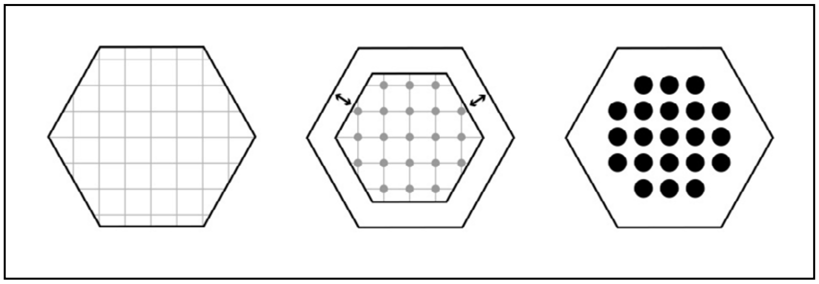

Fig. 5. Exemplary basic shape with defined grid (left), changing the buffer size until the correct number of dots can be arranged within (middle), the resulting dot arrangement (right).

5. Applications and limits

The two methods introduced above were implemented with D3.js and tested with a variety of datasets. The squarish dot arrangement works for a great variety of shapes and datasets (see Figure 6 for some examples). Depending on the shapes, the grids of dots are often not too difficult to compare and all dots lie within the respective shape. Therefore no dots overlap into neighboring areas. This method has the potential to communicate data in a new way. Additionally, the implemented algorithm works fast and can be used for interactive web-based applications.

For basic shapes the squarish dot arrangement method works well and the dots are displayed almost in a square (**Fehler! Verweisquelle konnte nicht gefunden werden.** left). This is the ideal case. For shapes with holes the dots are arranged around the holes but are potentially still arranged on an almost quadratic grid (**Fehler! Verweisquelle konnte nicht gefunden werden.** middle). The squarish shape is still visible and comparison of values seems possible. In very irregular shapes the squarish shape of the dot arrangement is no longer recognizable (**Fehler! Verweisquelle konnte nicht gefunden werden.** right). With this arrangement the comparison is more difficult, potentially only possible by counting the dots.

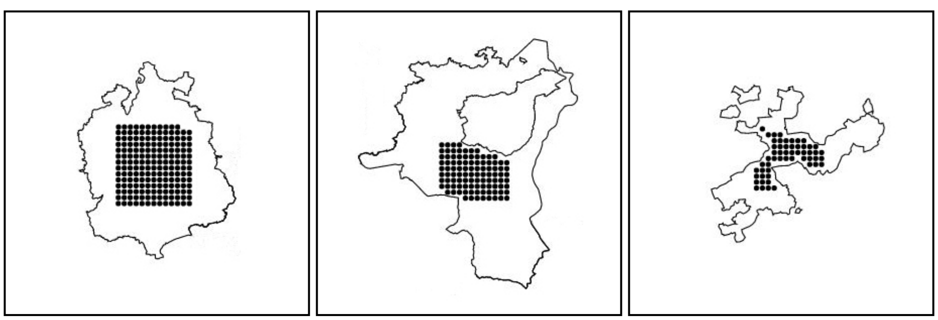

Fig. 6. A basic shape filled with a squarish dot arrangement (left), a shape with a hole filled with a squarish dot arrangement (middle), and an irregular shape filled with the squarish dot arrangement method (right)

Generally, we observe that as long as the pattern of the dots is quite regular or the number of dots is countable we may be able to perceive the displayed values. If there are uncountable numbers of, for example very small, dots then there is a tendency to compare the size of the surrounding area by completing the implied square (in cases where the display resembles a square). In those cases a hole in the shape can potentially be misleading. We assume that those shapes are rare or that it might be possible to eliminate the hole from the shape. Fig. 7 gives an example of an arrangement around a hole that might be difficult to interpret.

For very small shapes with many dots to show it is possible that not all dots can be arranged within the shape. If this case affects only a few shapes, there might be a possibility to zoom this shapes to a bigger scale and display the zoomed in shape with the dots in a separate part of the visualization.

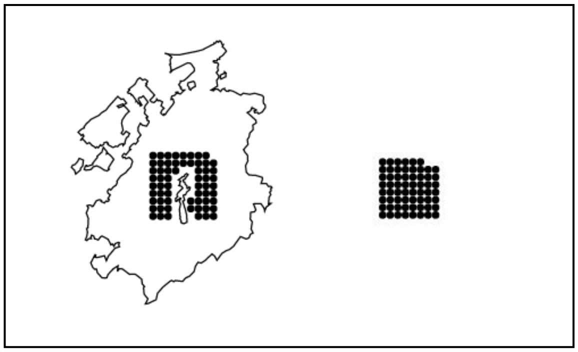

Fig. 7. Switzerland's canton Freiburg with a hole in its boundaries representing an actual lake. This is an example where the number of dots in the arrangement might be overestimated (compare the dot arrangement left to the almost complete square of dots to the right). However, in this case it would be possible to eliminate the lake from the shape boundary and allow for a better dot arrangement.

The buffer-based dot arrangement also works well with a variety of datasets. This method works best for small distances between dots and large numbers of dots. More dots are more difficult to count but they better represent the shape, as long as the buffer is not too wide.

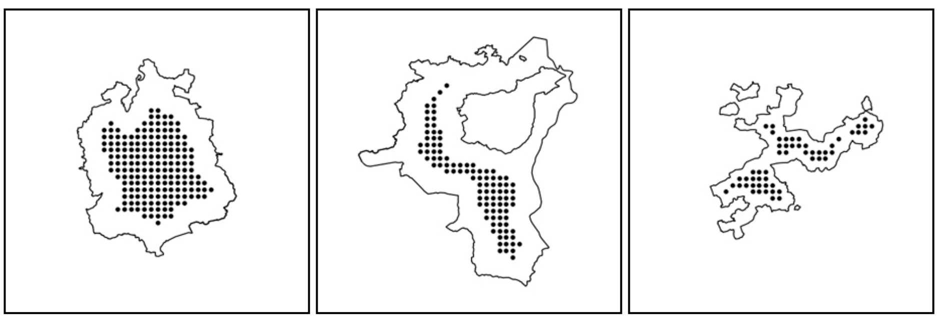

Fig. 8. A basic shape filled with the buffer-based dot arrangement (left), a shape with a hole filled with the buffer-based dot arrangement (middle) and an irregular shape filled with the buffer-based dot arrangement (right)

Figure 8 shows examples of the buffer-based dot arrangement. It uses the shapes introduced in Figure 3 and the same number of dots as displayed in the shapes in Figure 6. In basic shapes the buffer-based dot arrangement displays the dots nicely and the original outline of the areal feature is still basically visible (Fig. 8 left). However, in this arrangement it may be more difficult to compare two values. The arrangement is even more difficult when there is a hole in the shape. Then the dots are widely distributed and it is difficult to perceive them as an entity (Fig. 8 middle). But the shape of the basic outline is also nicely represented. Also with the buffer-based dot arrangement method it is most difficult to perceive the number of dots represented in irregular shapes (Fig. 8 right). In irregular shapes the dots are loosely distributed and look close to randomly distributed. The shape of the original outline can hardly be recognized. Sometimes a buffer of an irregular shape can divide the original shape in multiple disconnected parts.

In comparison with the squarish dot arrangement the buffer-based method would not need any zoom-in's on smaller shapes with a large number of dots. As the description of the algorithm details (see section 3.2), the highest dot to area ratio is used as a starting point for the calculations. But in fact the very small shapes also need to be handled separately. Otherwise the calculated distance between dots is very small and the buffer for the other shapes would be very large. Overall this would result in a difficult to read and potentially not very useful representation.

6. Conclusions

We presented two methods to arrange an absolute number of dots within a specific related area. The two algorithms are implemented and working. The examples give an indication of the potential applications and limitations of the methods. The implementation and usage of the methods for different values and shapes needs further testing. The ongoing research project "Atlas of the Ageing Society" will make further use of the developed methods and implement and test a wider range of datasets and the resulting visualizations.

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